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## RECENT ADDITIONS AND IMPROVEMENTS TO THE HALES BAR HYDROELECTRIC PLANT

by Adolph A. Meyer, M. ASCE

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# RECENT ADDITIONS AND IMPROVEMENTS TO THE HALES BAR HYDROELECTRIC PLANT

By: Adolf A. Meyer[1] - M. ASCE

A discussion of additions and improvements to a plant demands, first of all, a certain familiarity with the project as it was originally built. In the case of Hales Bar this introductory chapter is a specially interesting one, as we deal here with one of the pioneer hydroelectric plants in the country.

## I. History and Description of Initial Project

Just below Chattanooga, the Tennessee River abandons the course it had followed from Kingston and by a turn in a westerly direction cuts through the formidable Walden's Ridge. For 30 miles it passes through a narrow gorge, with a total drop of 30 feet. This gorge, called The Narrows, was a dangerous stretch for river navigation. In 1890 the lower river and the middle river were joined for navigation by the opening of the Muscle Shoals Canal. There naturally followed agitation for improvements of the navigation conditions in The Narrows, the dangerous stretch separating the middle river from the upper reaches. At about the same time, the first transmission of electric energy over moderate distances succeeded. So the two goals--better navigation and an electric power supply for the city of Chattanooga--were combined. Following promotions by citizens of Chattanooga, the Congress passed an act in 1904 which authorized the Secretary of War to grant permission to the city of Chattanooga to build and construct a dam in The Narrows. If Chattanooga failed to apply for permission within four months, permission could be granted to a private corporation or to individuals. The total cost of the project, except for the plans, equipment, and gates at the lock, was to be paid for by the contracting party. The deed for the lock,

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1. Head Civil Engineer, TVA, Knoxville, Tennessee

dam, and reservoir property was to be transferred to the government. In return, the act granted a 99-year right to generate power.

As the city of Chattanooga did not apply, permission was granted to C. E. James and J. C. Guild, who in 1905 organized the Chattanooga and Tennessee River Power Company and then transferred their rights to this company.

By the fall of 1905, the final site for the dam had been selected, designs prepared, and construction work was ready to begin. The costs were estimated at three million dollars; the time required for completion was assumed to be two years.

The project layout, figure 1, placed the navigation lock at one side of the river, the powerhouse at the other, and a straight overfall spillway in between. An earth embankment forms the barrier over the low flood plain between the powerhouse and the left shore. The total length of the barrier, shore to shore, is about 2,350 feet.

It is interesting to note that the general arrangement of the structures at Hales Bar is very similar to the arrangement used 30 years later for the layout of the neighboring projects at Chickamauga and Guntersville.

At the selected site rock was outcropping all across the river channel. The formation is Mississippian limestone, with its bedding nearly horizontal. The accepted geological theory of that time maintained that no solution channels could form in rock below the ground water level. It was this erroneous concept of the foundation rock which led to a long series of grave disappointments. Figure 2 shows a longitudinal section of the rock structure along the base line of the dam. It reveals the many interconnecting solution channels which honeycomb the formation as far down as 100 feet below the surface. As the cofferdams were advanced over this honeycombed rock, unwatering became more and more difficult. By the time about half of the spillway was built, unwatering by means of cofferdams became impossible and pneumatic caisson foundations had to be resorted to. This continuous fight against leakage delayed construction endlessly and correspondingly increased construction costs enormously. It was

April 1914, 8-1/2 years after the start of construction, when the plant was finally ready to go into commercial operation. The project costs, originally estimated at $3 million, had risen to $11.3 million.

The useful head created by the dam was 37 feet at low flow, which could be increased by about 3 feet by placing flashboards on the spillway crest.

The navigation lock has a main chamber 60 feet wide with a clear length of 265 feet. It is designed for a 9-foot navigation depth. Not much care was applied to the safety and ease with which vessels could approach and leave the locking chamber.

The basic layout of the powerhouse substructure is of a surprising simplicity. Eight buttress walls, each 10 feet thick, 97 feet long, and 94 feet high, form seven flumes, each 19 feet wide, which are separated from the forebay by a low concrete sill and a headgate about 30 feet high. In each of these flumes two units are mounted. The initial eight units are vertical tripple-runner Francis wheels; the six units installed in 1915 and 1916 are single-runner Francis wheels. The runner diameters vary between 61 and 82 inches; their operating speeds are 112.5 and 100 rpm. The total capacity of the fourteen units is 51,000 kw.

It is quite obvious that the arrangement of the waterways for the six runners of the initial units within one flume opening required great ingenuity. (See figure 3 - Powerhouse Cross Section, Units 1 to 8.) The different passageways are separated by concrete walls and steel draft tube liners. Needless to say, the hydraulic efficiency of this complicated setting was necessarily low.

The 14 generators are housed in a well-built concrete superstructure. At the shore end, a large indoor switching station adjoins the generating station. This switch house enclosed all the transformers and the 115,000-volt switching equipment. A 46,000-volt switching station was located on the roof of the building. A railroad track extends the full length of switch house and generator room.

The small turbine runners required a narrow spacing of the rack bars. In consequence, much trash handling had to be anticipated. To ease this situation, the

forebay upstream from the intake was fully enclosed, with a floating trash boom on its river side.

Measured by the standards of hydroelectric developments at the time of its inception, Hales Bar was well-built and adequately equipped when it started operation. However, the foundation leakage which had upset construction to such a large extent continued to make trouble. In spite of the fact that the dam foundation had been lowered as far as 30 feet below the original rock line and that a good amount of drilling and grouting had been performed in the solution zones, the filling of the reservoir produced seepage boils in the tailwater below the dam. These boils gradually increased in number. Attempts to stop the leakage by plugging up the suction inlets within the reservoir failed. Then, between 1919 and 1921 a program of asphalt grouting was carried out. Over 6,000 linear feet of 2-3/4-inch-diameter holes was drilled from the inspection gallery of the dam and over 75,000 cubic feet of asphalt was injected into these holes. This operation appeared successful, as the leakage was reduced to insignificant amounts. But by 1931 the leakage had again increased to about 200 cubic feet per second and by 1939 it reached 1,650 cubic feet per second.

In 1922, the Hales Bar property was acquired by the Tennessee Electric Power Company. In 1924, the new owner built a steam plant of 40,000-kw capacity adjacent to the hydro station. In 1939, the Tennessee Valley Authority acquired the Hales Bar hydro and steam plants.

## II. Arresting Leakage under Dam

In 1939 the water passing under the dam represented a yearly loss of more than 20 million kwh of energy. Furthermore, the continuous undermining of the foundation rock raised questions regarding the ultimate safety of the structure. Immediately following acquisition, TVA started to study means by which the leakage could be stopped. These studies indicated that for a permanent correction a cut-off wall penetrating solid rock below all the honeycombed areas would have to be constructed. To build such a wall without lowering the reservoir was an unprecedented feat. It was accomplished by drilling

a system of overlapping holes, 18 inches in diameter. The drill holes were lined with asbestos cement pipe and filled with concrete. Downstream from the cut-off wall a large amount of foundation consolidation was then performed under the dam. This work, carried out between 1941 and 1944, has been described in detail in a paper entitled "Flowing Water in Underground Channels, Hales Bar Dam, Tennessee," by L. A. Schmidt, Jr., M. ASCE, which is printed in the Transactions, 1945.

## III. Navigation Adjustments

After correcting the leakage the next project was the adjustment of the Hales Bar river stretch to the requirements of the improved Tennessee River navigation channel. Below Hales Bar, the TVA had already built the Guntersville Dam. Its headwaters provided a 9-foot channel to the Hales Bar lock, with only little dredging required at a few gravel bars. On the upstream side, Chickamauga Dam had been built 7 miles upstream from Chattanooga. In this 7-mile stretch between Chattanooga and the Chickamauga lock, the depth was insufficient during low flow periods, amounting to only 4 feet in some sections. When the Chickamauga site was selected, improvement of this river stretch either by dredging or by raising of the Hales Bar pool was contemplated. Comparative estimates indicated that raising the minimum headwater from elevation 626.25 to elevation 632.00 combined with a small amount of channel dredging offered the most economical solution. In order to raise the pool by this amount, piers and gates had to be installed. Two additional objectives also had to be considered. Space had to be provided for an additional lock to be built when the present lock which is of substandard length becomes inadequate for river traffic, and space was needed for an extension of the powerhouse. In order to build these additions in an economical fashion, parts of the old spillway had to be allotted for these future structures. These allotments, including 224 feet assigned to the future lock and 188 feet assigned to the powerhouse extension, shortened the spillway, originally 1200 feet long, to an over-all length of 788 feet. To compensate for the flood discharge capacity lost by this change in length it was necessary to lower the crest.

With 17 gate openings and piers 6 feet thick, the new crest had to be set at elevation 616, or 10.25 feet below the original one. The gates are of the radial type, with their top at elevation 635. The reservoir level is to be varied between elevation 632 and 634, leaving 1-foot freeboard on the gates at maximum pool.

Because the stability of the dam was adequate for the increased head, the design of the spillway changes did not offer any unusual problems (see figure 4). The piers were anchored into the old wier by reinforcing bars set in drill holes 12 feet deep. The concrete for the new crest was made 2 to 3 feet thick; careful bonding with the old concrete was called for and the reinforcement was anchored to the old concrete by dowels 5 feet on center. The piers support an operating deck at a level which provides clearance for all flood conditions. Two traveling hoists can be moved along this deck for raising and lowering the gates. The adjustment to the transverse joints in the old dam was done with great care; it was difficult because the joints were distributed in a most irregular pattern and some of the joints were active contraction joints while others were obviously frozen. As there had been a moderate amount of scouring below the old dam, tests were made in the hydraulic laboratory to find an apron form which would prevent further scour. The tests showed that by filling up the existing apron to elevation 588, a stable condition for practically all flows could be obtained. The same tests were used to establish the minimum length and height of the training walls at each end of the spillway. The wall at the powerhouse side was designed as a bulkhead to withstand full water load during the time when it would form a part of the cofferdam for the powerhouse extension.

All the spillway alterations had to be constructed without lowering the level of the reservoir. To carry them out economically, extensive use was made of structural steel bulkheads which could be re-used in many alternate positions. For the large amount of line drilling, special jumbos were devised. A good description of the construction methods has been published elsewhere.[2]

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2. A. H. Weber - Hales Bar Dam: Rebuilt and Ready for More Power - Engineering News-Record - October 19, 1950

The raising of the reservoir level solved the navigation problems in the upper stretch of the Hales Bar pool. But to satisfy reasonable demands on traffic safety and efficiency, the lock itself had to be improved. It has already been mentioned that the length of the lock chamber is less than the standard adopted for the upper Tennessee River. However, as the locks at Wilson Dam also are of substandard length, the shorter lock chamber at Hales Bar will not act as a serious impediment until improvements have been made at Wilson. Therefore, improvements of the existing lock were decided upon, with space allotted for a new lock to be built at the time river traffic demands it. The object of the changes was, first of all, the improvement of the approach conditions both downstream and upstream, a reduction of navigation interruptions during flood stages, the betterment of the mooring and towing facilities in the lock chamber, and miscellaneous equipment modernizations. At the lower end of the downstream guard wall troublesome eddies hindered safe navigation at frequent flows. Tests in the hydraulic laboratory indicated that good approach conditions would exist if the wall would be lengthened by 560 feet. To build this wall without unwatering, 15 sheet pile cells, 27 feet in diameter and filled with tremie concrete, were constructed with their top projecting above low water level. On top of these cells, a continuous concrete wall 29 feet high was placed. The old guard wall was raised to the same elevation. The old and new wall together form a guard wall 750 feet long, with the top at elevation 625. The wall will be visible at all flows up to 300,000 cfs. On the land side, three new mooring cells help guide traffic into the lock chamber. Similar improvements were made to the upstream approach. Along the rocky cliff on the land side, which was unprotected in the past, a new guide wall 425 feet long was built. An inverted U-shaped concrete box is supported on two rows of precast concrete piles which are anchored into the rock. Traffic impacts are transferred by the horizontal girder to articulated concrete struts which connect to anchors on the rock bluff. The old upstream guard wall was improved by the addition of curtain walls between the piers to stop troublesome side currents in the approach bay.

While the dam was able to withstand the increased head within normal design criteria, the analysis of the river wall of the lock chamber indicated tensions at the base for the raised pool level. A triangular block of concrete had to be added on the river side in order to obtain a wider base. To make sure that this block would actually buttress the old concrete, a grouting plane was formed near the base of the block on a slope perpendicular to the principal stress. During the cold weather season and with the lock chamber empty, grout of 30-pound-per-square-inch pressure was introduced into this sealed-off joint. In this fashion, a permanent prestress was established in the new block (see figure 5). In the lock chamber itself, three floating mooring bitts and a towing unit for barges were installed. New valves were placed into the filling culverts, and the miter gate operation mechanism was rearranged and its capacity increased. Figure 6 shows the old and the improved locks in plan side by side, and figure 7 shows a photograph of the improved lock.

The raising of the pool level called for some adjustments in the reservoir. Additional land had to be bought, additional clearing had to be done, and at Chattanooga some sewer adjustments had to be carried out.

Construction on the improvements to dam and lock were started in 1946 and completed in 1950.

## IV. Additions and Improvements to Power Facilities

The third step of the improvement program at Hales Bar deals with the power installation. When Hales Bar was built, there was no flow regulation within its drainage area of 21,800 square miles. The variations in flow were extreme, varying between an extreme low of 3,300 cfs and a maximum flow of record of 460,000 cfs. Today, there are upstream of Hales Bar a large number of reservoirs with a useful storage of almost 10,000,000 acre-feet. The flow characteristics of the river have changed markedly, as indicated by the duration curves for natural and regulated flow shown on figure 8.

The useful storage in the Hales Bar pool, with only 2 feet of fluctuation, is very limited, amounting to only 13,100 acre-feet. The adjoining reservoir on

the upstream side, the Chickamauga pool, has a useful storage of 329,000 acre-feet. In order to utilize the regulation made possible by the large reservoir at Chickamauga, it was desirable to have the draft of the turbines at Hales Bar at least equal to the turbine draft at Chickamauga. During a day of maximum station output, the four units at Chickamauga draw about 40,000 cfs. The corresponding figure for the old station at Hales Bar is 20,000 cfs. A new turbine installation with draft equal to the old station's was therefore selected. It consists of two Kaplan wheels with a nominal rating of 24,300 kw each at 36-foot head, with a maximum discharge capacity of about 22,000 cfs. Their addition increases the station output, which amounted to 238 million kwh during the average year of unregulated flow and 369 million kwh during the average year of regulated flow, to 594 million kwh.

The construction of the two units necessitated some further changes of the power facilities as follows:

The additional 62,100-kva capacity of the new units made the existing transmission facilities inadequate. New 161-kv system ties were provided to replace the existing 115-kv tie line.

New step-up transformers and switching equipment located outdoors were provided to replace the existing indoor equipment. This removed from the building a very serious fire hazard and made available valuable building space for needed operating facilities which would otherwise have to be built as part of the new control building.

In addition, a new control center for the new units and the switchyards had to be provided. In order to provide economical operation, with a minimum number of operators, it was decided to abandon the operating center of the old hydro, as well as the one of the steam station and to provide a new central control building for all these stations and the switchyard.

Other desirable improvements included the improvement of the ventilation system in the old station. During the hot summer months the air-cooled generators of the old station were subject to serious capacity limitations. Improvements in the ventilation of the generator room helped to reduce these limitations.

To provide space for the switchyards and control building, the part of the forebay immediately upstream

from the earth embankment was reclaimed by a fill. To obtain stable conditions able to carry switchyard structures, the mud and silt which had accumulated over the old flood plane were first removed by dredging. With material borrowed from sand and gravel banks below the dam, the fill was brought to a level slightly above the water level of the forebay. Then compacted clay was placed to the final subgrade above flood level. In this manner room was provided for a 161-kv switchyard, a future 46-kv switchyard and a new control building, centrally located between hydro plant, switchyards, and steam station. The transformer yard was placed on the downstream side of the earth embankment. (See figure 9.)

The new switchyard fill separated the intake for the condensing water supply for the steam station from the forebay. By building a pipe line under this fill, with a drop inlet on the forebay side and a small inlet chamber at the old intake structure, the function of the intake was maintained.

As already pointed out, the new units were to be placed at the river end of the old station, where 188 feet of the old dam was left in reserve for this work when the spillway was altered. In order to reduce the costly work of lowering the spillway crest, the space allocation for the powerhouse had to be kept to the minimum requirement for a workable station layout. Each of the unit blocks with hydraulically efficient waterways required a width of 78 feet. A trashway 15 feet wide which existed at the end of the old powerhouse to serve as a means for trash disposal had to be moved to the river end of the enlarged station. That left only 17 feet for the width of the service bay. (See figure 10.) This unusually tight situation was helped by two features: The two new units are operated by remote control from the new control building. No operating personnel is stationed in the new plant, which eliminates any need for locker rooms, wash room, etc. Furthermore, at the end of the old station there was a sluiceway bay 18 feet wide. The sluiceway had never been operated. It could therefore be filled with a concrete plug. The upper part of this bay was then incorporated into the new station. By this means, the railroad track running through the old generator room could be extended so that the crane of the new station covered it for a car length for unloading of

equipment. The service bay provided room for a stair well and an equipment hatch connecting to the levels of the two main galleries, the station sump, and on three different levels the air compressor and air receivers, the lubricating oil storage and purification plant, the station service electrical equipment, and the $CO_2$ storage.

In developing the unit blocks, great effort was made to provide efficient waterways, compact arrangement of the main equipment, and good communications. At the intake side, the upstream face lines up with the face of the old station intake. The new deck forms a continuation of the old deck, with identical width. Water enters the bellmouthed intake, subdivided into three passageways for each unit, through trashracks mounted on the upstream face. If emergency unwatering so requires, stoplogs can be set into the trashrack guides. Each opening is 46 feet high and 23 feet wide, resulting in a velocity for the gross area at the entrance of 3 feet per second. The upper lip of the bellmouth is 9 feet below the lowest normal reservoir level. The intake gate openings, just downstream from the bellmouth, are 37 feet high. For closure, one set of intake gates is provided. Each gate is made up of two leaves. The gates for two openings are slide gates, while the gate for the third opening is of the fixed-wheel type. Stoplogs to allow the unwatering of one intake opening are on hand. The gate leaves are stored in storage pits in the intake deck, while storage for the stoplogs is provided in the upper part of the trashrack slots. A gantry crane of 30-ton capacity handles the gates, stoplogs, and trashracks.

An unusual complication developed from aligning the new intake with the old one. This arrangement placed the face of the intake 49 feet upstream from the face of the dam. The deep corner pocket would tend to produce eddy flows. Hydraulic Laboratory tests showed that they affected the flow pattern in the intake in a very undesirable way. At the riverside unit, the flow into the passageway next to the dam was almost nil. It was estimated that the resulting turbulence in the intake would cause a power loss of about 1.5 million kwh per year. Various types of flow guides to correct the flow pattern to the intake were tested in the laboratory. Based on these tests, two guides were installed, one at

the river end of the units and one between the two units. (See figure 11.) Because the cofferdam clearance would not allow them to be built in the dry while the cofferdam was in place, they had to be precast and lowered into slots after the cofferdam was removed. They were made of hollow concrete sections, one placed on top of the other and the hollow space finally filled with gravel to lend stability to the guides.

The unit blocks are 161 feet long. The riverward block is 78 feet wide, while the landward block, which includes the service bay, is 95 feet wide. To separate the service bay from the old powerhouse by an effective contraction joint without removing more of the dam than was necessary for space requirements, a line of holes was drilled to rock through the old concrete to establish a plane of weakness. The center line of the unit is 99 feet from the draft tube exit. The area at the exit is 1515 square feet, resulting in an exit velocity of 6.3 feet per second at maximum discharge. (See figure 12, Powerhouse Cross Section.) The center line of distributor is at elevation 599, or 6 feet above minimum tailwater. This allowed the generator room floor to be established at elevation 630, which is 13.4 feet below the generator room of the old station. To provide unloading facilities from the track extension on the level of the old generator room, a balcony was provided at that level in the service bay. It also provides space for the rotor erection. It connects to a balcony which runs the full length of the new station. At its river end, a stairway leads up to a balcony at the level of the spillway deck, with a door in the river wall connecting to the deck. A shelter for the operators of the spillway cranes is provided just inside of this door.

With the outside diameter of the generator, which operates at 69.2 rpm, being 46 feet 6 inches and with erection space for the runner and the bearing bracket being required on the generator room floor, the width of the new station had to be larger than the width of the old station. (See figure 13.) The downstream wall had to be offset by 10 feet 6 inches. The roof, on the other hand, could be kept on the level of the old station roof. The twin-governor cabinet is located

downstream of the unit and is centered between them. A stair connects from the governor to the pipe gallery below. This gallery extends the full length of the station and provides convenient access to the thrust bearings, the turbine pits, and the scroll cases.

The upstream and downstream walls of the generator room are 5-foot-thick concrete walls. This type of wall afforded simplicity of construction, avoided the need of a crane girder, provided room for ventilating ducts, and formed a solid support for the runways of the 275-ton crane and for the steel roof frames. Walls of glass enclose the area between the crane rails and the roof. The river end wall is a 3-foot-thick concrete wall.

While efforts were made to balance the volume outline of the new station with the superstructure of the old station, none of the architectural formalities of the old station were repeated in any way. (See figure 14.) The addition is a modern functional structure contrasting with the old structure, which carries the mark of its own time. The same difference shows up on the inside of the station, but here it is emphasized by the contrasts in appearance between the pioneer generators at one end of the hall and the new modern equipment at the other end.

Good design by the electrical engineers made it possible to place all electrical equipment serving the unit, i.e. the switchgear, the neutral reactors and breakers, and the exciter cubicles, all on the generator room floor. Most of this equipment is placed in a very orderly fashion and very accessible under the balcony along the upstream wall. From the switchgear the generator oil pressure pipe-line-type cables are carried through the upstream wall to a cable tunnel under the new intake deck. This tunnel, which also houses the control cables, terminates in a pulling chamber at the junction of the new and old deck. From there to a pulling chamber at the shore end of the old deck, station service power and controls are enclosed in a number of heavy wall transite pipes which, together with the steel pipes containing the generator cables, run exposed along the upstream wall of the old station. A new cable tunnel built into the earth embankment along the old switch building then takes the generator leads and

control cables from the new and also from the old station to the transformers and the new control building, respectively.

The control building is located adjacent to the switchyard on ground reclaimed from the forebay. It is an L-shaped building covering an area of approximately 5,400 square feet. The substructure is a monolithic concrete box; the superstructure consists of steel framing with brick and tile walls. Besides the main control room, it houses the relay, the communication and the battery room. In addition, it contains facilities for the operators, such as file room, locker and wash room, and a kitchen. It is air-conditioned. It serves as the central control room for the old and the new hydro station, for the steam station, and for the switchyards. The new hydro units are operated by remote control, while the old station requires the presence of one operator on the floor. By combining the controls into one building, five operators per shift could be saved.

With the removal of the high-tension equipment and the old control room from the switch building, a good amount of space became available there. The building was altered to provide some urgently needed facilities for plant operation. These include office space for the superintendent and his assistant and for clerical help, a test room, a first-aid room, and a large assembly room. A new machine shop and storage rooms were also provided. For visitors, an overlook of the generator room with lobby and washrooms could be arranged. Adjacent to the switchyard there was room to provide a large parking area for operators. Nearby, on the hillside along the access road, a parking area for the numerous visitors could be established, which offers a good view of the plant layout.

The construction of the two units called for the solution of some unusual problems. As the forebay level had to be maintained at all times, the upstream cofferdam had to replace temporarily the concrete dam and therefore required a high degree of safety. It had to withstand normally a head of 50 feet. Seventy-foot-diameter steel sheet pile cells were used. How

special templates were developed for driving these cells has been described elsewhere.[3]

While the upstream cofferdam was unusual by the magnitude of the head it had to withstand, the downstream cofferdam also had its peculiar problem. In plan it was U-shaped to enclose the area of excavation for the units proper and for the tailrace. The setting of the unit called for 45-foot-deep rock excavation at the low point of the draft tube. One side arm was formed by the new spillway training wall; the other was formed by cells connecting along the old tailrace to the old station. With horizontal bedding joints in the rock and with clay present in some of these joints, what was going to happen after the rock inside the cofferdam was removed? It was feared that the rock supporting the cofferdam, especially the narrow shelf between the old and new tailrace, might slide into the new excavation. After studying different schemes to prevent sliding, a system calling for excavation step-by-step was adopted. In the first step, excavation was carried only 62.5 feet downstream from the center line of units. After the unit blocks were built up to elevation 569, they could act as a strut and then the rest of the draft tube area was excavated. When the draft tubes were built and the contraction joint between units along the top slab was grouted, this slab could act as a strut and the tailrace was then excavated. By proceeding in this manner, the shear in the cofferdam foundation was limited at all times to about 15 pounds per square inch.

Actual construction work on the powerhouse additions and improvements was started in 1951. The new units were put into commercial operation during July and December 1952. The majority of the improvements have been completed, but a small amount of work is still in progress.

## V. Summary

The cost of the changes, additions, and improvements at Hales Bar is, in round figures, as follows:

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3. Templates Take Trouble Out of Driving 70-Foot Cofferdam Cells by O. R. Bengston - Engineering News-Record, January 17, 1952

| | | | |
|---|---|---|---|
| A. | Foundation Treatment | | $ 2,730,000 |
| B. | Increasing the Reservoir Level | | |
| | Dam | $2,309,000 | |
| | Lock | 1,307,000 | |
| | Reservoir | 1,026,000 | |
| | Miscellaneous | 128,000 | |
| | | | 4,770,000 |
| C. | Installation of Units 15 and 16 and Betterments | | 15,000,000 |
| | | Total | $22,500,000 |

The gains obtained from these expenditures have been discussed in detail above. They represent improvements of the safety of the structures, better navigation facilities at the lock and in the river channel, substantially increased power output with more economical and dependable operation. A good illustration of the modernized project is given by figure 15.

All engineering and construction work for TVA is under the direction of C. E. Blee, M. ASCE, Chief Engineer. The planning is the responsibility of James S. Bowman, M. ASCE, Chief Water Control Planning Engineer; designs of structures, as well as specifications and inspection of equipment, is under the direction of Robert A. Monroe, M. ASCE, Chief Design Engineer. George K. Leonard, M. ASCE, is Chief Construction Engineer.

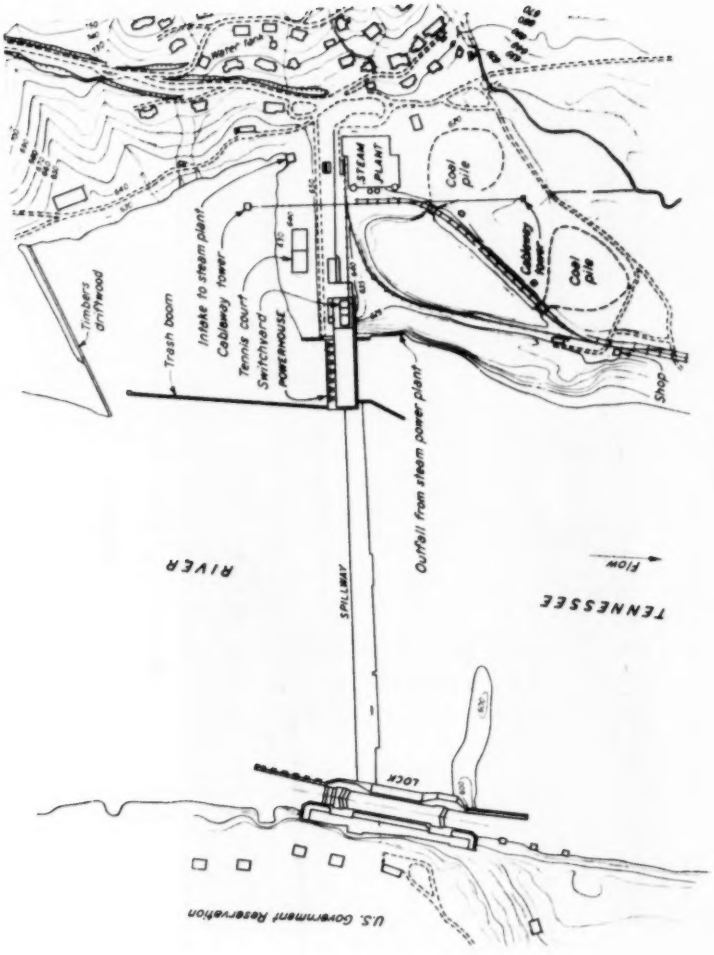

Water tank
STEAM PLANT
Coal pile
Coal pile
Coal pile
Cableway tower
Cableway tower
Intake to steam plant
Trash boom
Timbers driftwood
Tennis court
Switchyard
POWERHOUSE
Shop
Outfall from steam power plant
RIVER
TENNESSEE
FLOW
SPILLWAY
LOCK
U.S. Government Reservation

Figure 1

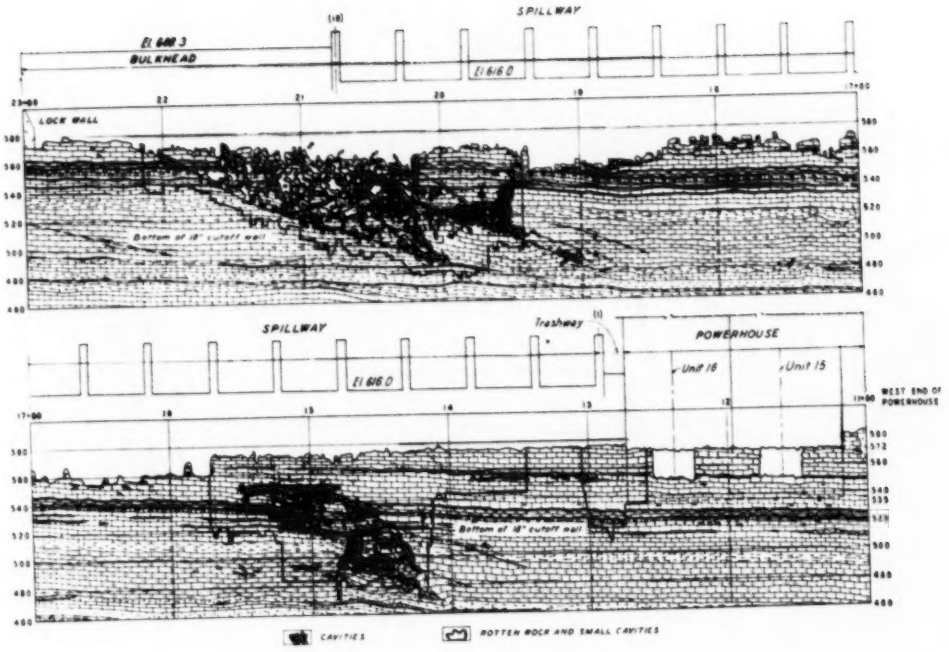
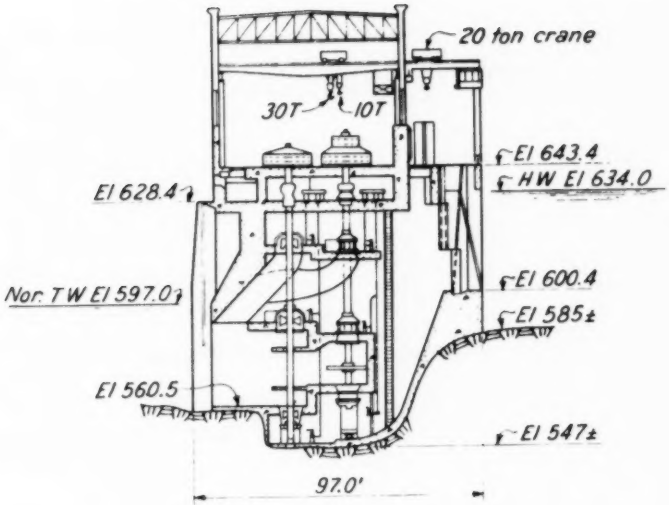

SPILLWAY
El 648.3
BULKHEAD
El 616.0
LOCK WALL
Bottom of 18' cutoff wall
SPILLWAY
Trashway
POWERHOUSE
El 616.0
Unit 16
Unit 15
WEST END OF POWERHOUSE
Bottom of 18' cutoff wall
CAVITIES
ROTTEN ROCK AND SMALL CAVITIES

Figure 2




SECTION - POWERHOUSE
UNITS 1 - 8

Figure 3

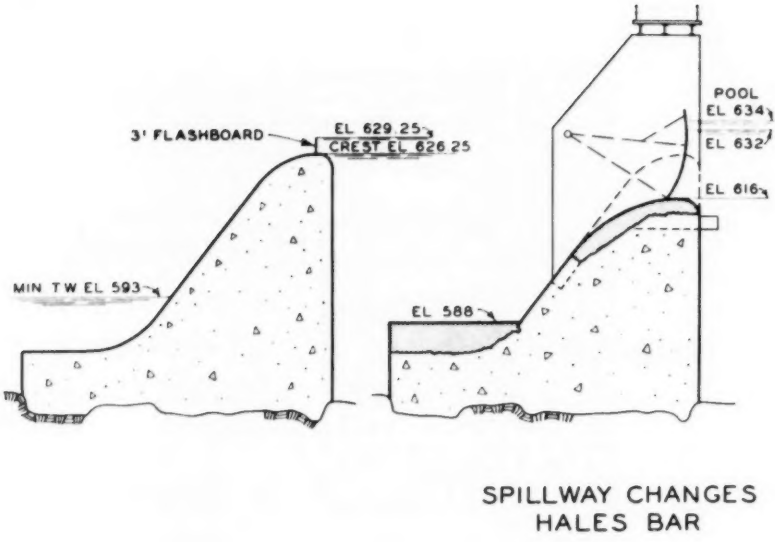

3' FLASHBOARD
EL 629.25
CREST EL 626.25
MIN TW EL 593
EL 588
POOL
EL 634
EL 632
EL 616
SPILLWAY CHANGES
HALES BAR

Figure 4

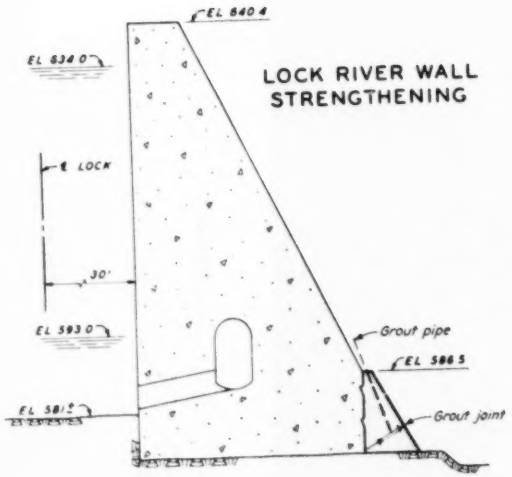



Figure 5

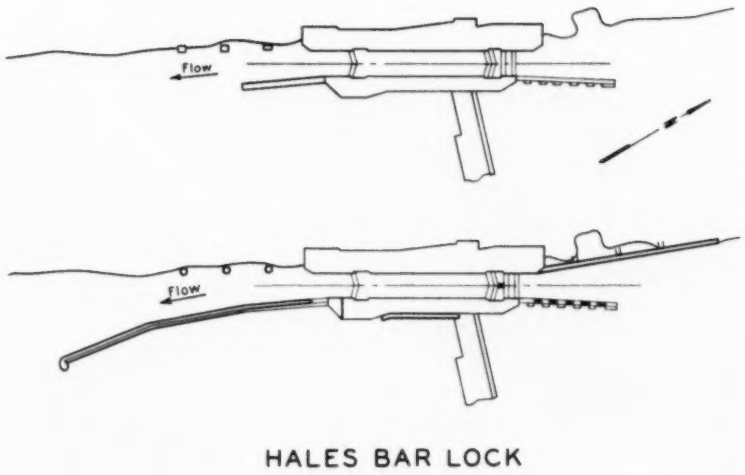



Figure 6

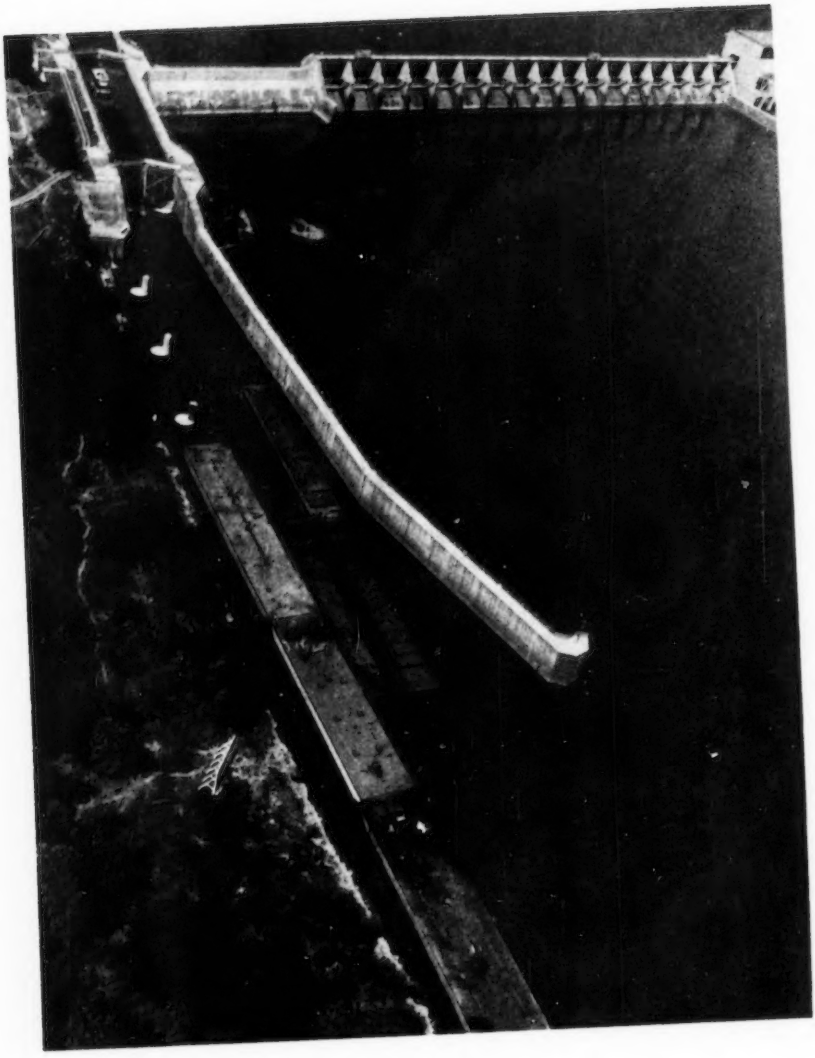
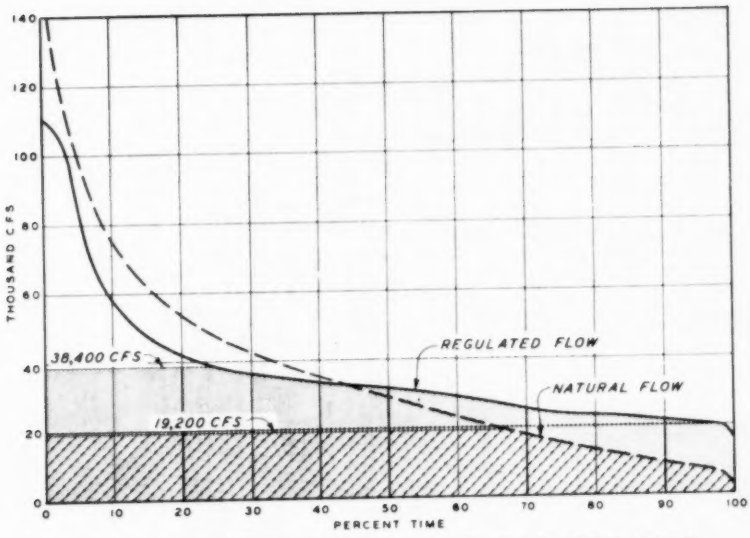


Figure 7




DURATION OF FLOW - HALES BAR PROJECT
1921 - 1932

Figure 8

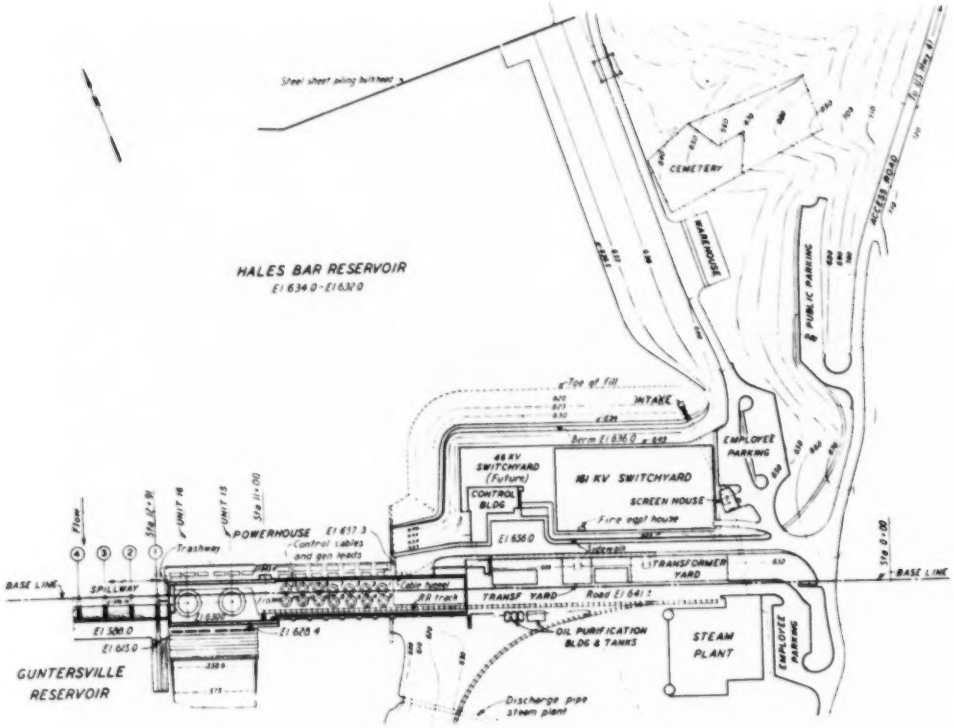

Steel sheet piling bulkhead
HALES BAR RESERVOIR
El 634.0 - El 632.0
CEMETERY
WAREHOUSE
PUBLIC PARKING
ACCESS ROAD
Top of fill
INTAKE
Berm El 636.0
EMPLOYEE PARKING
46 KV SWITCHYARD (Future)
CONTROL BLDG
161 KV SWITCHYARD
SCREEN HOUSE
Fire roof house
Flow
Trashway
POWERHOUSE El 617.3
Control cables and gen leads
El 636.0
Sta 11+00
TRANSFORMER YARD
BASE LINE
SPILLWAY
RR track
TRANSF YARD
Road El 641.7
El 598.0
El 615.0
El 620.4
OIL PURIFICATION BLDG & TANKS
STEAM PLANT
EMPLOYEE PARKING
GUNTERSVILLE RESERVOIR
Discharge pipe steam plant

Figure 9

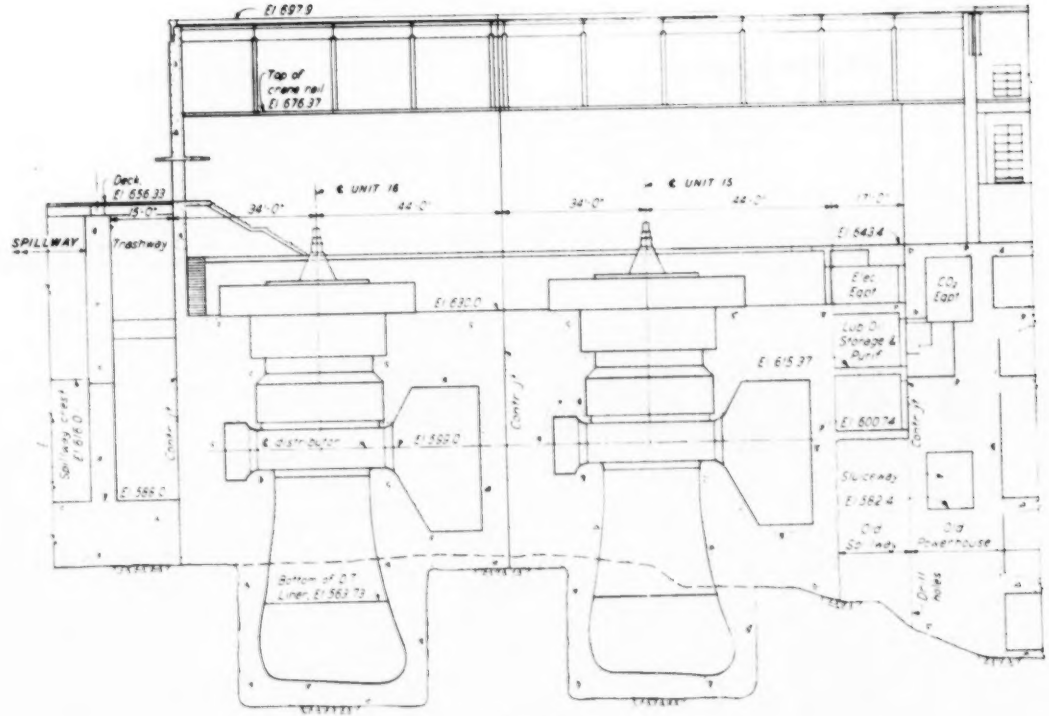

El 697.9
Top of crane rail El 676.37
Deck El 656.33
SPILLWAY
Trashway
℄ UNIT 16
℄ UNIT 15
34'-0"
44'-0"
34'-0"
44'-0"
17'-0"
15'-0"
El 643.4
El 630.0
Elec Equi
CO2 Equi
Lub. O. Storage & Purif.
El 615.37
El 600.74
Spillway crest El 616.0
El 585.0
℄ Str. Bottom
El 580.0
Contr. J.
Contr. J.
Contr. J.
Sluiceway El 562.4
Old Sluiceway
Old Powerhouse
Dr. II Rules
Bottom of D.T. Liner El 563.73

Figure 10

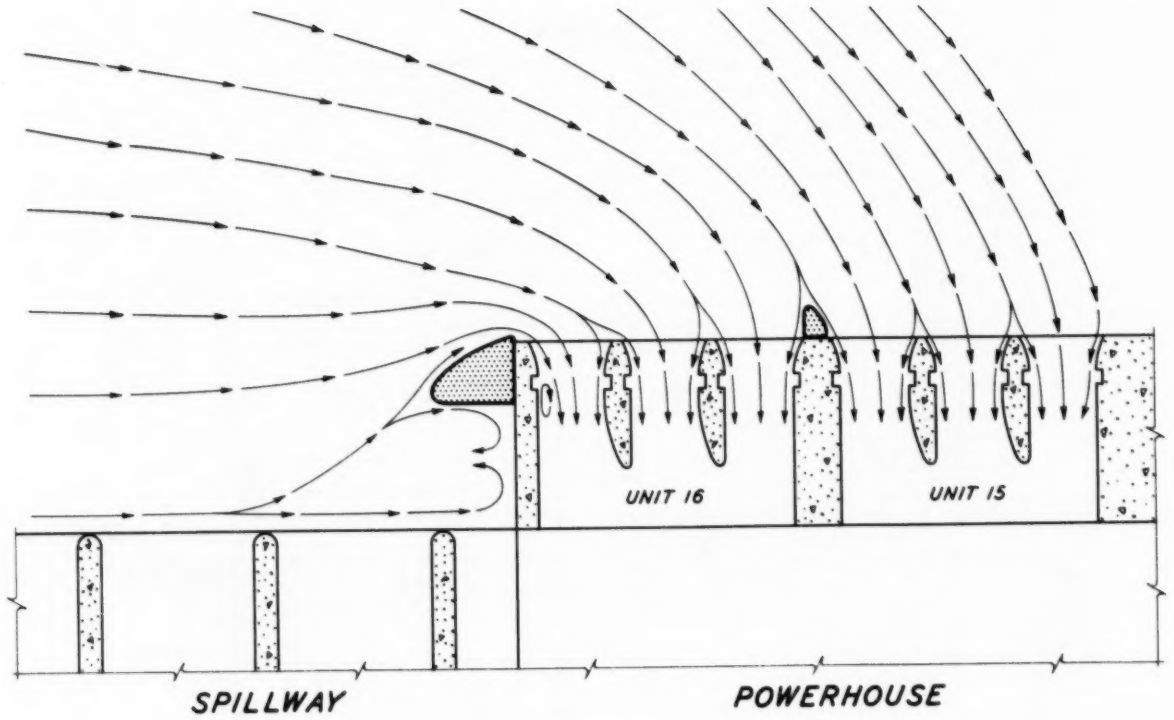
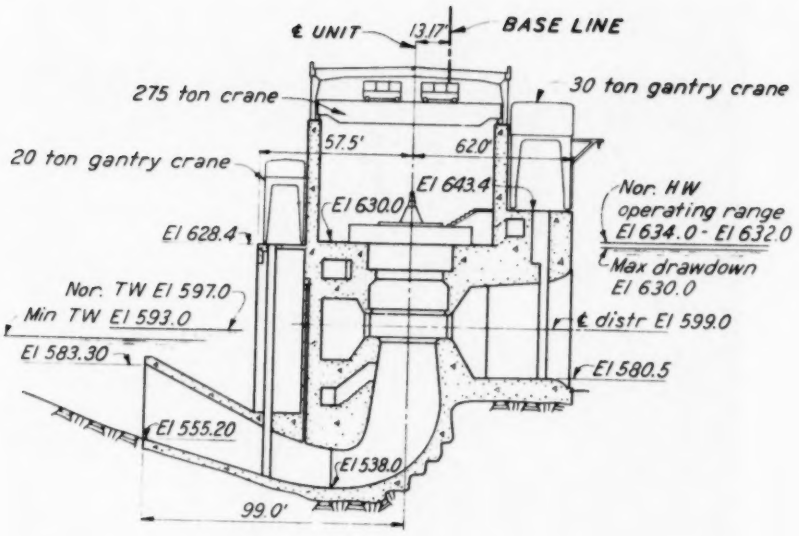



Figure 11




SECTION - POWERHOUSE
UNITS 15 & 16

Figure 12

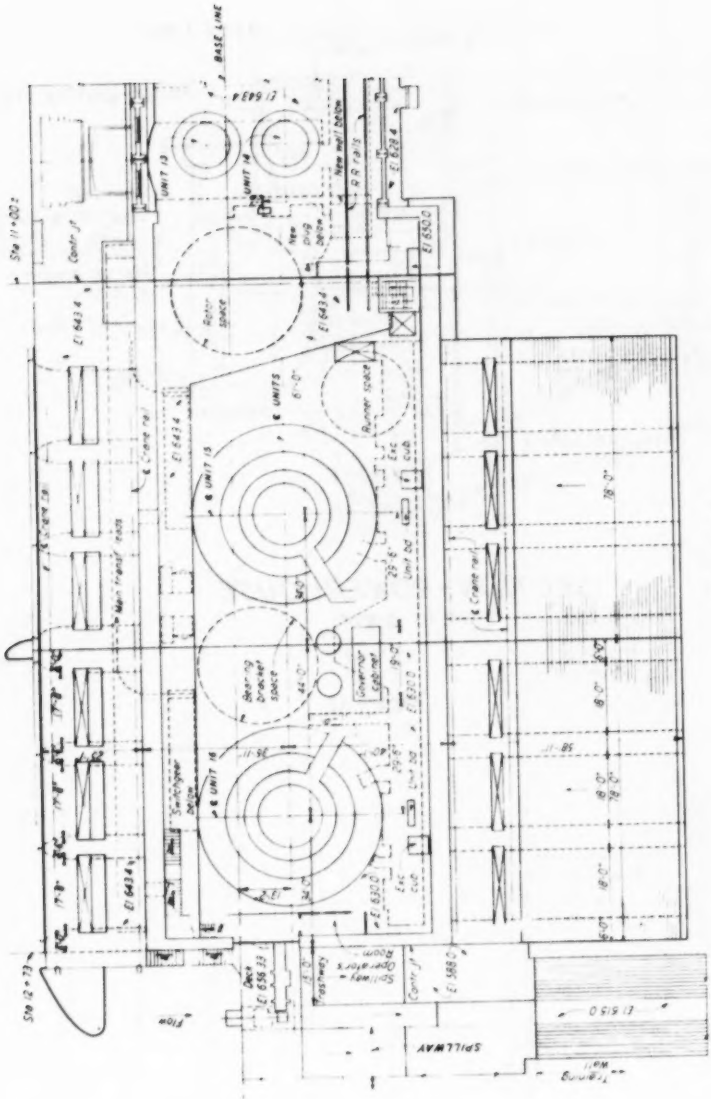



Figure 13

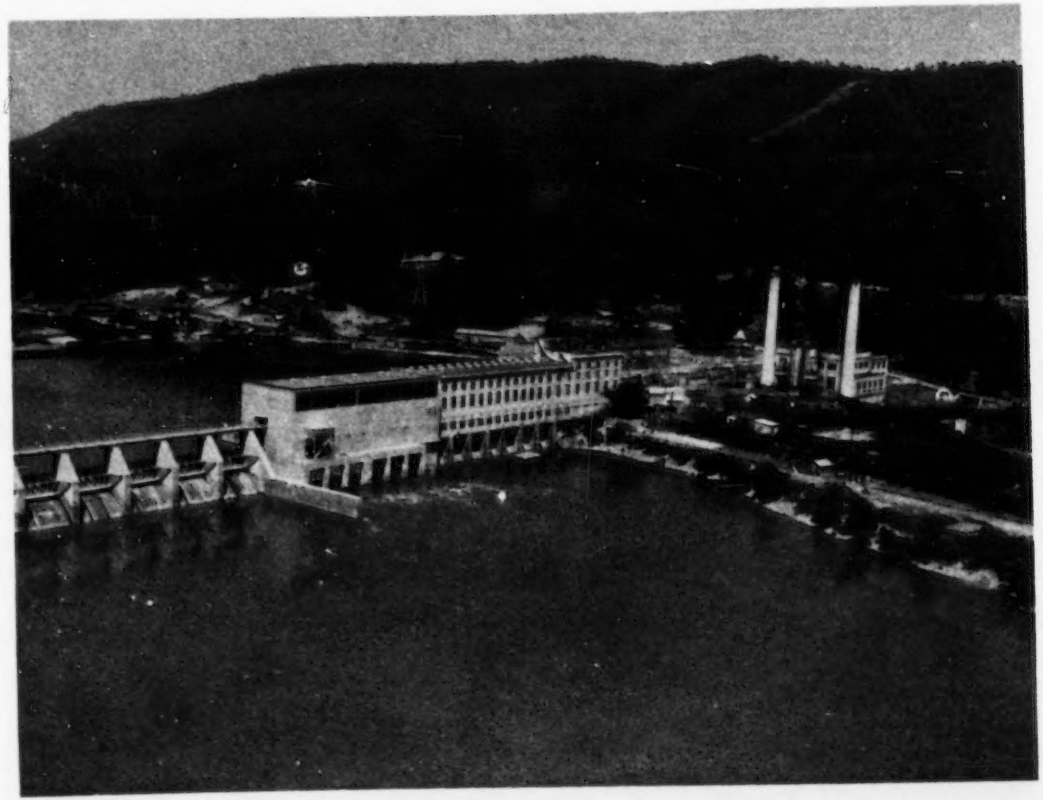


Figure 14

Figure 15